5 **(a)** Explain why the electric potential near an isolated proton is positive.

....

....

....

....

.... [3]

(b) An isolated metal sphere is positively charged and has radius R, as shown in Fig. 5.1.

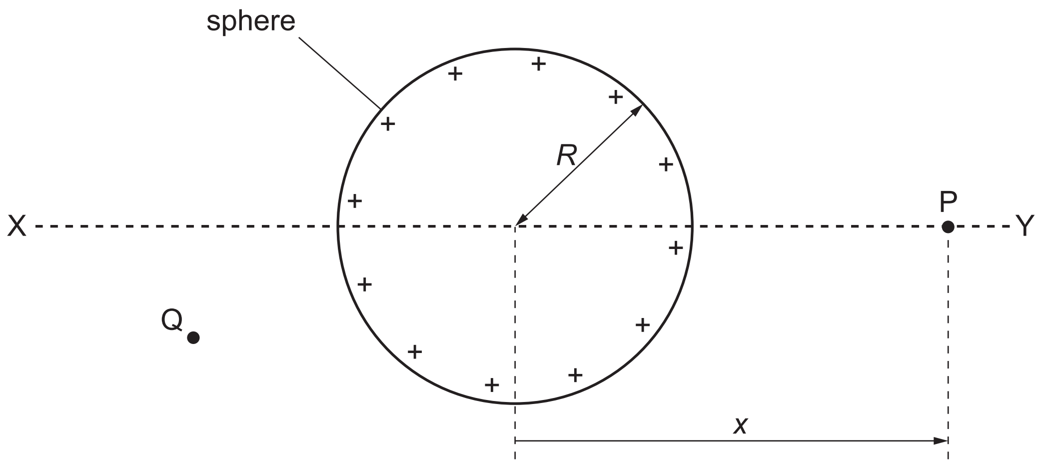

Fig. 5.1

Line XY passes through the centre of the sphere.
Point P lies on line XY at a variable displacement x from the centre of the sphere.
Point Q is at a fixed position that is not on line XY.

The electric field strength at the surface of the sphere is E_0.

(i) On Fig. 5.1, draw an arrow at point Q to show the direction of the electric field at that point. [1]

(ii) On Fig. 5.2, sketch the variation of the electric field E at point P with x for values of x between $x = -3R$ and $x = 3R$. Do **not** include the region inside the sphere between $x = -R$ and $x = R$.

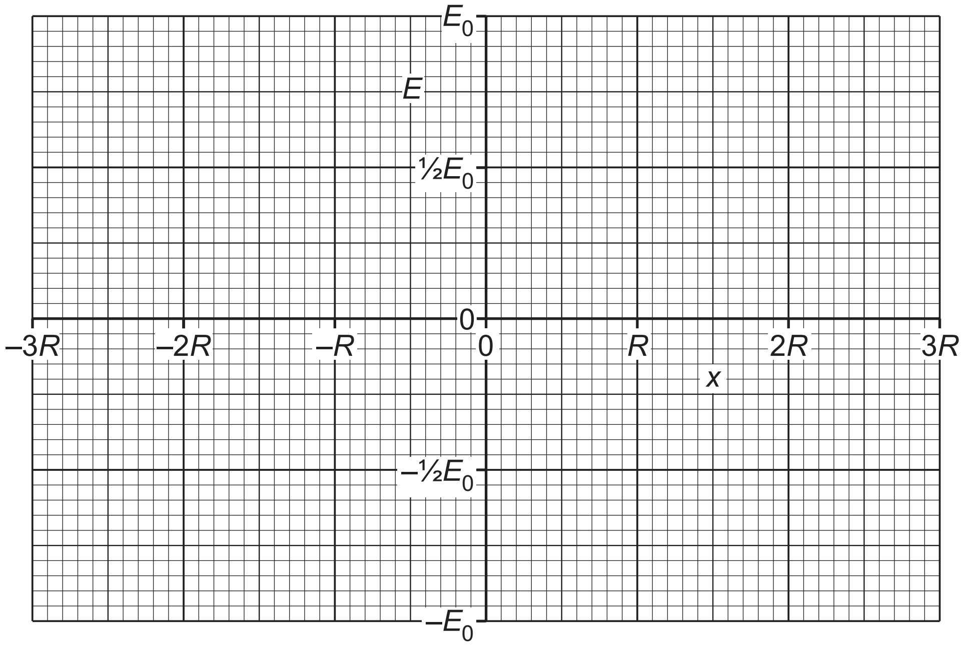

Fig. 5.2

[3]

(c) The proton and the electron in a hydrogen atom are separated by a distance of 5.3×10^{-11} m.

Calculate the electric potential energy of the proton and the electron.

electric potential energy = ... J [2]

6 **(a)** Define electric field at a point.

....

.... [1]

(b) An isolated conducting sphere in a vacuum has a capacitance of 69 pF.
The charge on the sphere is +83 pC.

(i) On Fig. 6.1, draw field lines to represent the electric field outside the sphere due to the charge on the sphere.

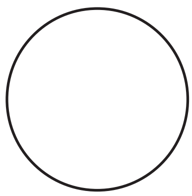

Fig. 6.1

[2]

(ii) Calculate the electric potential at the surface of the sphere.

electric potential = ... V [2]

(iii) Determine the radius of the sphere.

radius = ... m [2]

(iv) Calculate the electric field strength E at the surface of the sphere. Give a unit with your answer.

E = ... unit .... [2]

(c) The sphere in **(b)** is discharged by connecting it to earth (0 V) through a resistor of resistance 120 MΩ.

Calculate the time taken for the charge to fall to 26 pC.

time = ... s [2]

5 **(a)** Define electric potential at a point.

....

....

.... [2]

(b) A hydrogen atom may be considered to consist of a proton and an electron separated by a distance of 120 pm, as shown in Fig. 5.1.

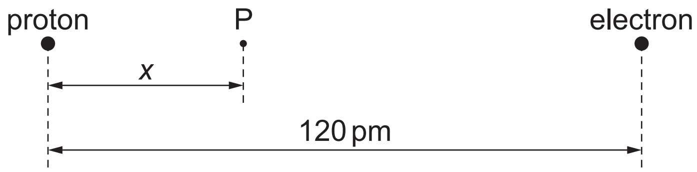

Fig. 5.1

The two particles may be considered as point charges.

Point P lies on the line joining the electron and the proton and is at a variable distance x from the proton.

(i) Show that the electric potential V at point P when x = 10 pm is equal to 130 V.

[2]

(ii) Calculate, to two significant figures, V when x = 30 pm.

V = ...V [2]

(iii) On Fig. 5.1, draw a cross (×) at one position, other than infinity, where the electric potential is zero. [1]

(iv) On Fig. 5.2, sketch the variation of V with x between x = 10 pm and x = 110 pm.

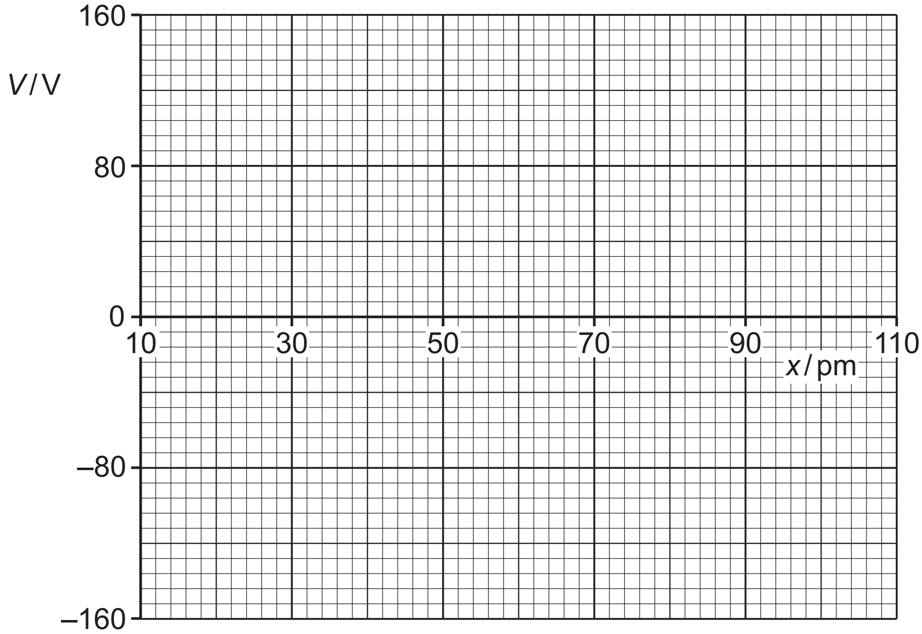

Fig. 5.2

[3]

5 **(a)** Define electric potential at a point.

....

....

.... [2]

(b) An isolated solid metal sphere of radius *r* is given a positive charge.

The potential at the surface of the sphere is 9.0×10^4 V. At a distance of 3*r* from the centre of the sphere, the electric field strength is 2.0×10^5 N C^{-1}.

(i) Determine the electric field strength at the surface of the sphere.

electric field strength = ... N C^{-1} [2]

(ii) Show that the radius of the sphere is 5.0 cm.

[2]

(iii) Calculate the charge on the sphere.

charge = ... C [2]

(iv) Use your answer in **(b)(iii)** to determine the capacitance of the sphere.

capacitance = ... F [2]

6 Two parallel metal plates X and Y are separated by a distance of 0.041 m, as shown in Fig. 6.1.

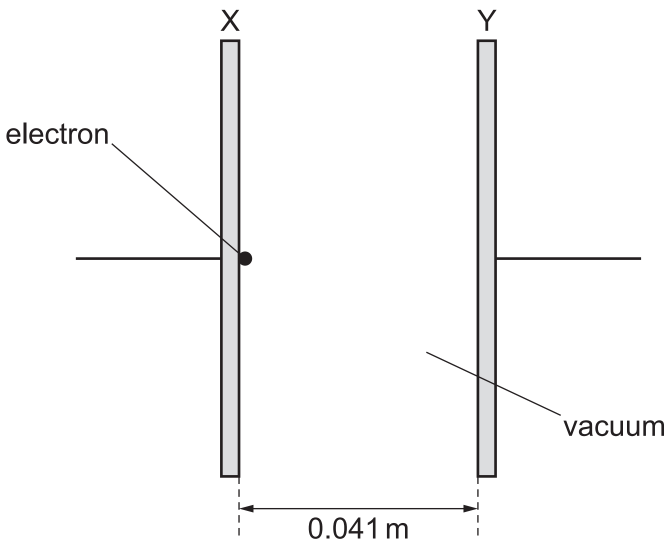

Fig. 6.1

There is a vacuum between the plates. An electron is at rest at the centre of plate X.

A potential difference (p.d.) of 58 kV is applied across the plates. This causes the electron to accelerate towards plate Y.

(a) On Fig. 6.1, use the symbols + and – to indicate which of plates X and Y is the positive plate and which is the negative plate. [1]

(b) **(i)** Calculate the electric field strength *E* between the plates. Give a unit with your answer.

E = ... unit .... [2]

(ii) Determine the acceleration of the electron.

acceleration = ... $m\,s^{-2}$ [2]

(c) Many electrons are now accelerated from rest from plate X to plate Y in Fig. 6.1. When the electrons hit plate Y, the absorption of their kinetic energies results in the emission of electromagnetic waves.

(i) Show that the minimum wavelength of these electromagnetic waves is 21 pm.

[3]

(ii) State the region of the electromagnetic spectrum that contains these waves.

.... [1]

(iii) Explain how these electromagnetic waves may be used to form images of internal body structures.

....

....

....

.... [2]

2 A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.

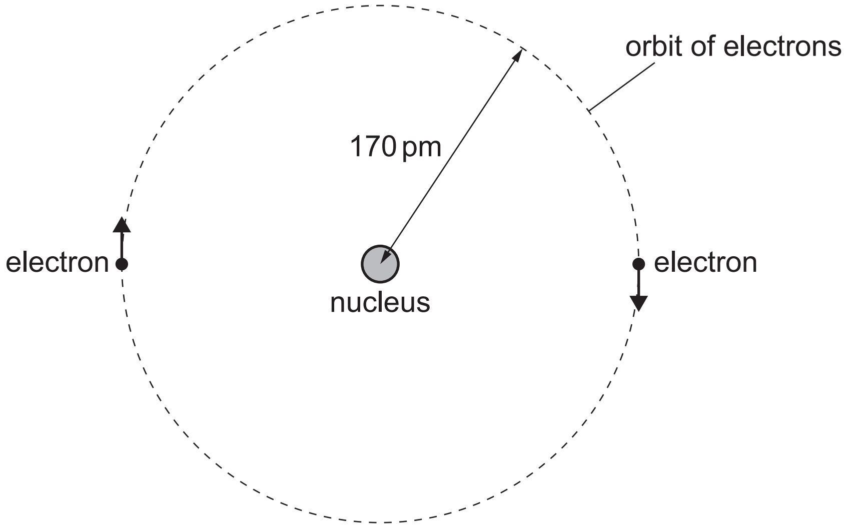

Fig. 2.1

(a) State Coulomb's law.

....

....

.... [2]

(b) **(i)** State the charge on the nucleus, in terms of the elementary charge *e*.

charge = ... *e* [1]

(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N.

[1]

(c) Assume that the force in **(b)(ii)** is the only force on the electrons.

(i) Calculate the speed of the orbiting electrons.

speed = ... $m s^{-1}$ [2]

(ii) Calculate the period of the orbit of the electrons.

period = ... s [2]

(d) In practice, the orbit of each electron is affected by the presence of the other electron.

(i) For the position of one of the electrons, determine the ratio

$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}.$$

ratio = ... [2]

(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron.

....

.... [1]

2 **(a)** The magnitude of the gravitational potential on the surface of a planet of radius R is ϕ. The planet can be considered to be an isolated sphere.

On Fig. 2.1, sketch the variation of the gravitational potential with distance x from the centre of the planet for values of x between R and $4R$.

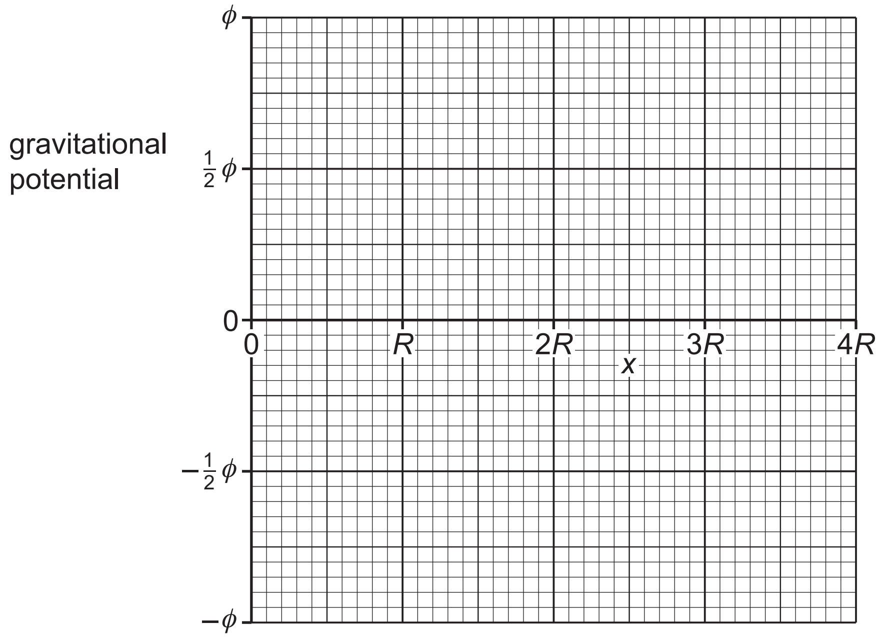

Fig. 2.1

[3]

(b) A satellite is in a geostationary orbit above the Earth. At time $t = 0$, the magnitude of the gravitational potential due to the Earth at the location of the satellite is ϕ.

On Fig. 2.2, sketch the variation of the gravitational potential due to the Earth at the location of the satellite for values of t between $t = 0$ and $t = 24$ hours.

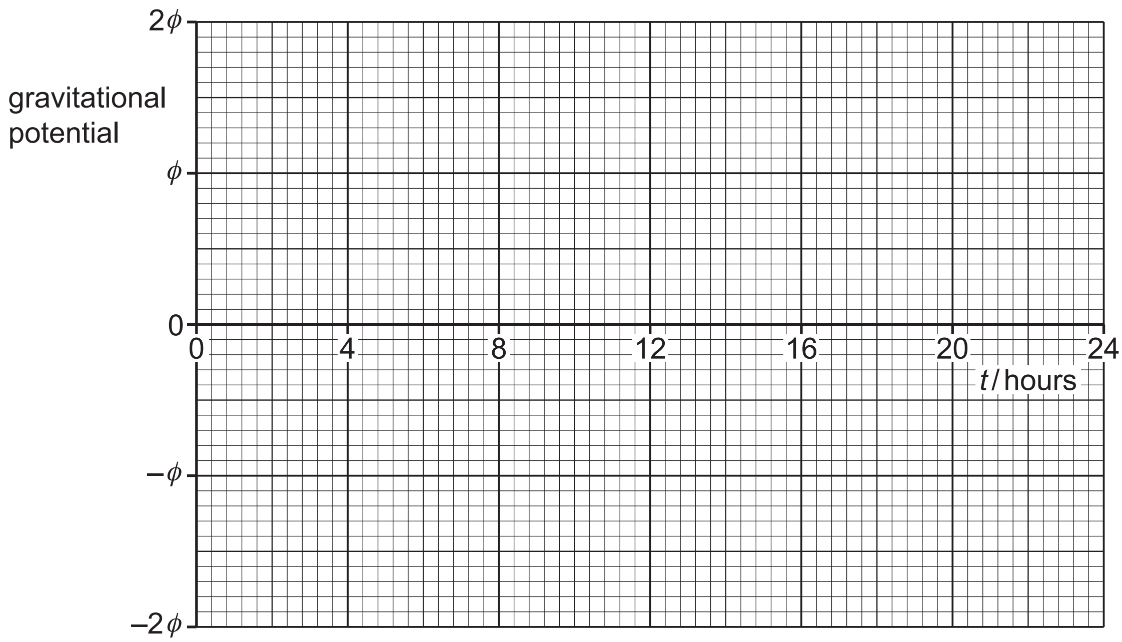

Fig. 2.2

[2]

(c) The electric potential difference (p.d.) between two parallel plates is V, as shown in Fig. 2.3.

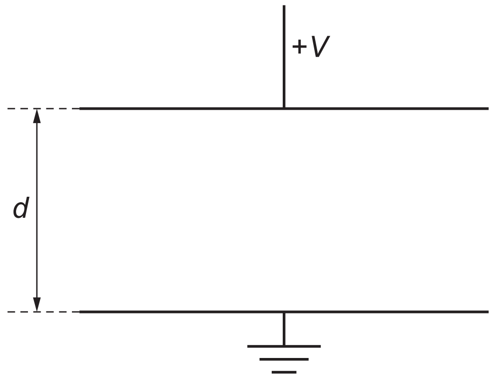

Fig. 2.3

The distance between the plates is d. The region between the plates is a vacuum.

On Fig. 2.4, sketch the variation of the electric potential with distance from the positive plate.

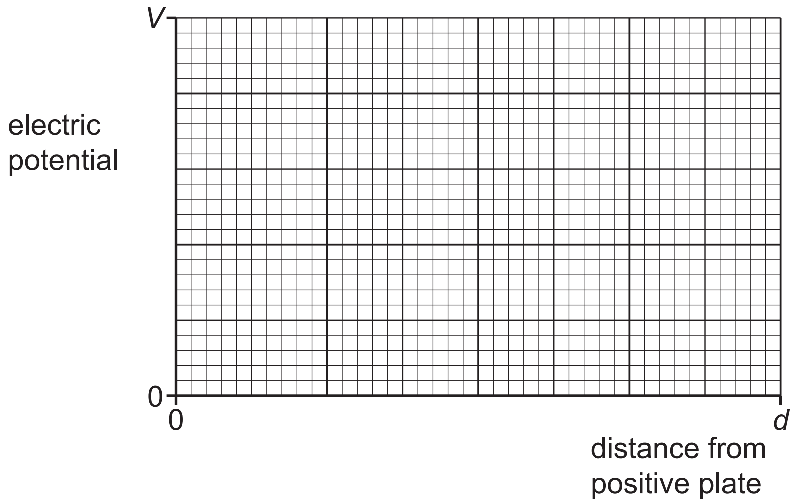

Fig. 2.4

[2]

6 **(a)** State Coulomb's law.

....

....

.... [2]

(b) Fig. 6.1 shows an isolated hollow conducting sphere that is positively charged.

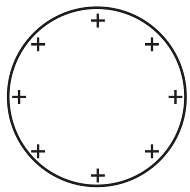

Fig. 6.1

On Fig. 6.1, draw field lines to represent the electric field outside the sphere. [3]

(c) Fig. 6.2 shows the variation of the electric field strength E with distance x from the centre of the sphere in **(b)**.

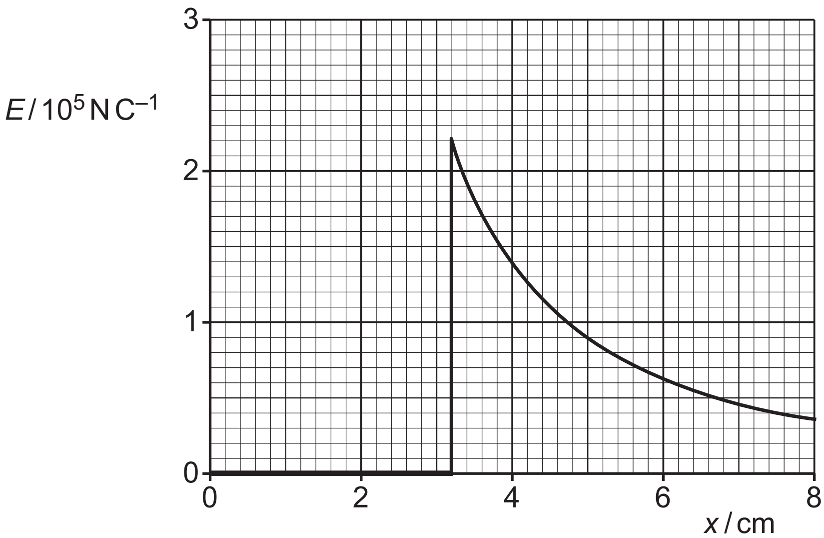

Fig. 6.2

(i) Determine the radius, in cm, of the sphere.

radius = ... cm [1]

(ii) Calculate the charge on the sphere.

charge = ... C [3]

(iii) Suggest an explanation for the fact that the electric field inside the sphere is zero.

....

....

.... [1]

5 **(a)** State the relationship between electric field and electric potential.

....

....

.... [2]

(b) Two charged isolated insulating spheres X and Y are near to each other, as shown in Fig. 5.1.

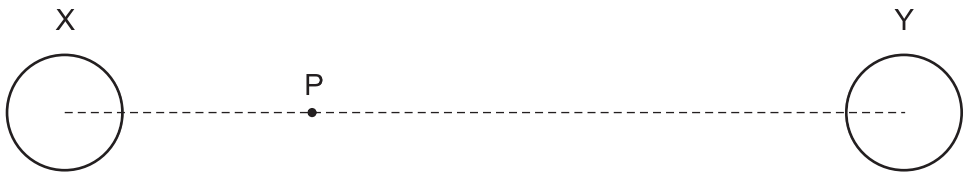

Fig. 5.1

P is a point on the line joining the centres of the spheres.

Explain why it is **not** possible for the total electric potential and the resultant electric field to simultaneously be zero at point P.

....

....

....

....

.... [3]

(c) The magnitudes of the charges on spheres X and Y in Fig. 5.1 are Q and $2Q$ respectively. The spheres may be considered as point charges at their centres.

Point P is a distance x from the centre of sphere X.

The electric potential at point P is zero.

(i) Show that the distance y of point P from the centre of sphere Y is equal to $2x$.

[2]

(ii) State an expression, in terms of Q, x and the permittivity of free space ε_0, for the electric field strength E_X at P due to sphere X.

E_X = ... [1]

(iii) Determine an expression, in terms of Q, x and ε_0, for the resultant electric field strength E at point P due to the two spheres.

E = ... [2]

5 **(a)** Define electric potential at a point.

....

....

.... [2]

(b) Two isolated charged metal spheres X and Y are near to each other in a vacuum. The centres of the spheres are 1.2 m apart, as shown in Fig. 5.1.

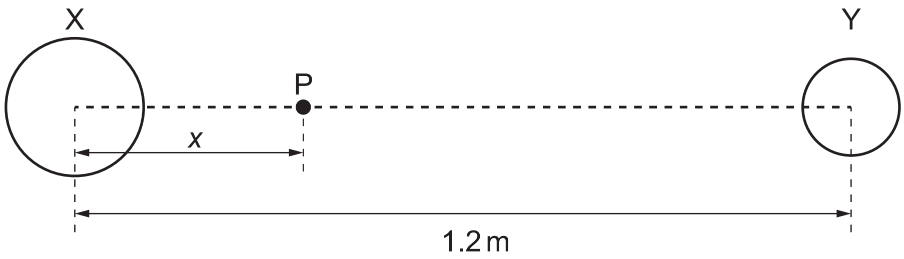

Fig. 5.1 (not to scale)

Point P is on the line joining the centres of spheres X and Y and is at a variable distance x from the centre of X.

Fig. 5.2 shows the variation with x of the total electric potential V due to the two spheres.

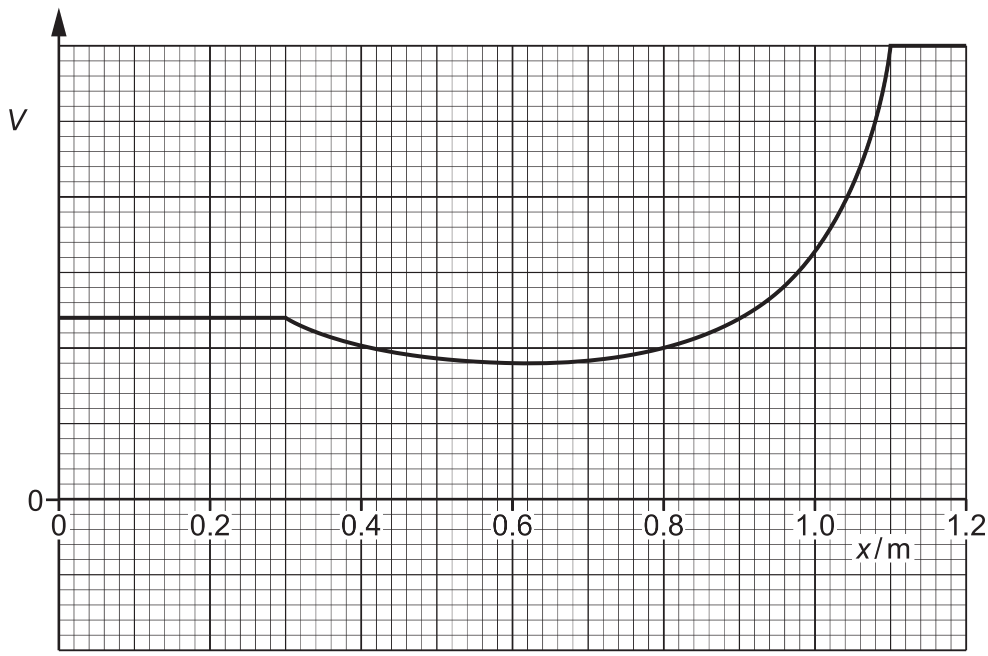

Fig. 5.2

State **three** conclusions that may be drawn about the spheres from Fig. 5.2. The conclusions may be qualitative or quantitative.

1 ....

....

2 ....

....

3 ....

....
[3]

(c) A proton is held at rest on the line joining the centres of the spheres in **(b)** at the position where $x = 0.60\,\text{m}$.

The proton is released.

Describe and explain, without calculation, the subsequent motion of the proton.

....

....

.... [2]

5 **(a)** Define electric field.

....

....

.... [2]

(b) Fig. 5.1 shows two parallel conducting plates that are in a vacuum. The plates are separated by a distance of 6.7 cm and have a potential difference (p.d.) of 430 V between them.

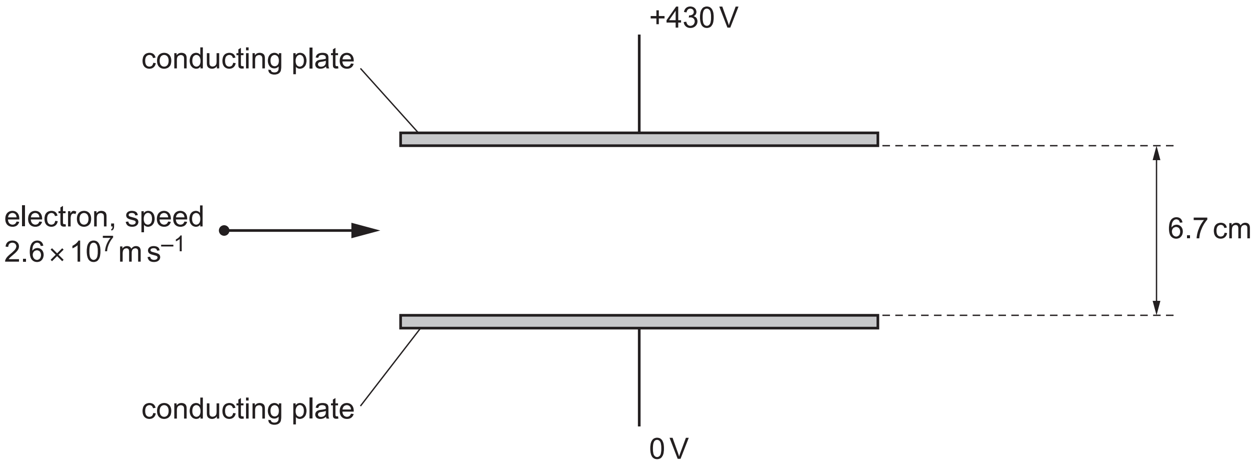

Fig. 5.1

(i) On Fig. 5.1, draw four field lines to represent the electric field between the plates. [2]

(ii) Determine the strength E of the electric field between the plates.

E = ... $\mathrm{N\,C^{-1}}$ [2]

(iii) An electron travels at a speed of $2.6 \times 10^7\,\mathrm{m\,s^{-1}}$ towards the region between the plates, as shown in Fig. 5.1.

On Fig. 5.1, draw the path of the electron as it moves between and beyond the plates. [2]

(c) A uniform magnetic field is now applied in the region of the electric field in Fig. 5.1, so that the electron in **(b)(iii)** travels undeviated through the region.

(i) Determine the direction of the uniform magnetic field.

.... [1]

(ii) Explain, with reference to the forces exerted by the two fields on the electron, why the path of the electron is undeviated.

....

....

.... [2]

(iii) Determine the flux density B of the uniform magnetic field. Give a unit with your answer.

B = ... unit .... [2]

5 **(a)** An object travels in a circle at constant speed.

State the names of **two** quantities that vary during the motion of the object.

1 ....

2 ....
[2]

(b) A charged particle of mass m and with charge q enters a region of uniform magnetic field, perpendicular to the field lines. The magnetic flux density is B.

The particle travels in a circle with period T and radius r.

(i) By considering the magnetic force acting on the particle, show that

$$B = \frac{2\pi m}{qT}.$$

[3]

(ii) The particle is an alpha particle. The period of the circular motion is 2.5 μs.

Calculate B.

B = ... T [2]

(iii) A second alpha particle is in the same uniform field. It travels in a circle of radius $2r$.

State and explain how the periods of the motion of the two particles compare.

....

....

.... [1]

(iv) The speed of the alpha particle in **(b)(ii)** is $1.1 \times 10^6\,\mathrm{m\,s^{-1}}$. An electric field is applied so that this particle now moves with constant velocity.

Use your answer in **(b)(ii)** to calculate the electric field strength E. Give the unit with your answer.

E = ... unit .... [2]

4 An electron in a metal rod moves randomly about a mean position. When an alternating voltage is applied to the ends of the rod, the mean position can be considered to oscillate with simple harmonic motion along the axis of the rod. Fig. 4.1 shows the variation with time t of the displacement x of the mean position from a fixed point on the axis of the rod.

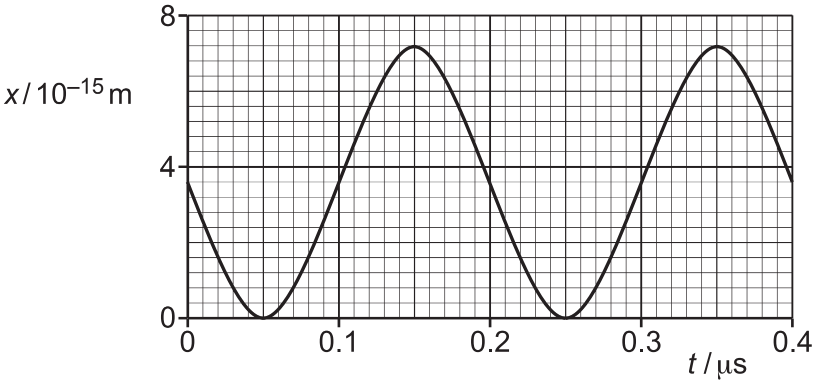

Fig. 4.1

(a) **(i)** Determine the amplitude of the oscillations.

amplitude = ... m [1]

(ii) Determine the angular frequency of the oscillations.

angular frequency = ... rad s^{-1} [1]

(iii) Use your answers in **(a)(i)** and **(a)(ii)** to show that the maximum drift speed v_0 of the electron is $1.1 \times 10^{-7}\,m\,s^{-1}$.

[2]

(b) The rod has a cross-sectional area of $4.3\,cm^2$ and contains a number density of conduction electrons (charge carriers) of $8.5 \times 10^{28}\,m^{-3}$.

All of the conduction electrons in the rod may be assumed to be oscillating in phase with, and with the same amplitude as, the oscillation shown in Fig. 4.1.

(i) Use the information in **(a)(iii)** to calculate the magnitude I_0 of the maximum current in the rod.

I_0 = ... A [2]

(ii) On Fig. 4.2, sketch the variation of the current I in the rod with time t between $t = 0$ and $t = 0.40\,\mu s$.

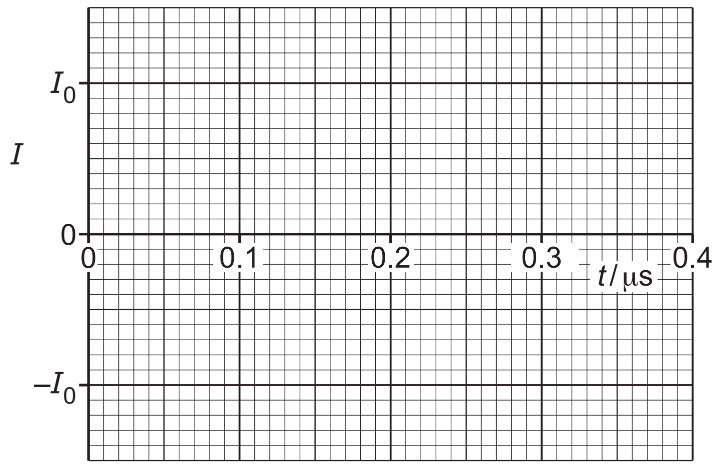

Fig. 4.2

[2]

(iii) Use your answers in **(a)(ii)** and **(b)(i)** to determine an expression for I in terms of t, where I is in A and t is in s.

I = ... [2]

(iv) Determine the root-mean-square (r.m.s.) current in the rod.

r.m.s. current = ... A [1]

5 **(a)** State Coulomb's law.

....

....

.... [2]

(b) Two identical oil droplets are in a vacuum. The centres of the droplets are a distance of 3.8×10^{-6} m apart. The droplets have equal charge and exert an electric force on each other of magnitude 6.3×10^{-17} N.

Determine the magnitude of the charge on each droplet.

charge = ... C [2]

(ii) On Fig. 5.1, draw four lines to represent the electric field between the plates. [3]

(c) One of the oil droplets in **(b)** is now placed between two horizontal metal plates, as shown in Fig. 5.1.

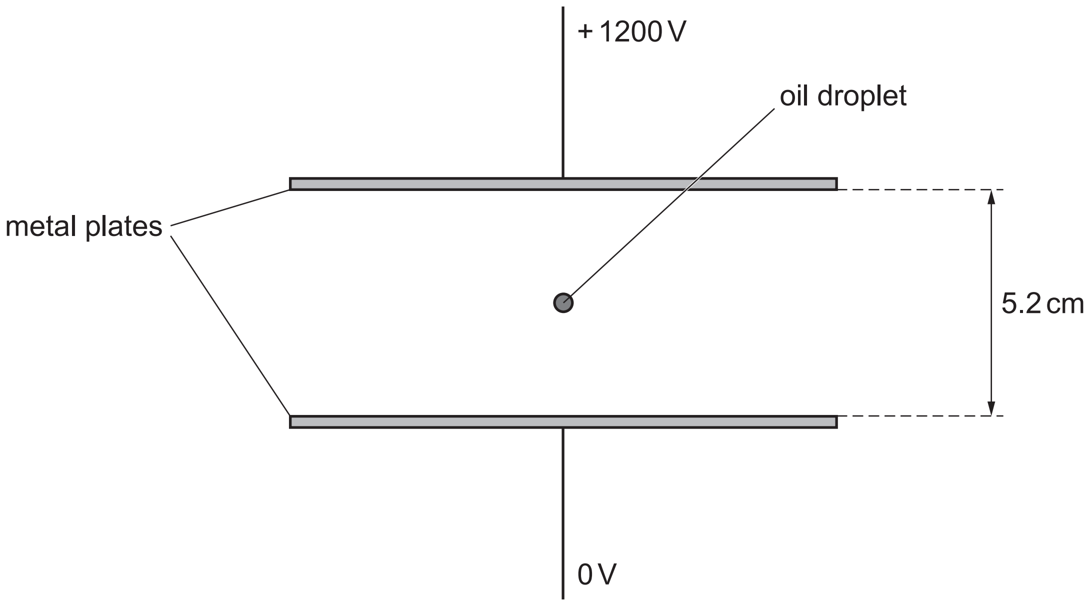

Fig. 5.1 (not to scale)

A potential difference (p.d.) of 1200 V is applied between the plates, with the top plate at the higher potential. The oil droplet is stationary and in equilibrium.

(i) State the sign of the charge on the oil droplet.

.... [1]

(iii) The distance between the plates is 5.2 cm.

Determine the mass of the oil droplet.

mass = ... kg [3]

5 **(a)** Define electric potential at a point.

....

....

.... [2]

(b) Two isolated charged metal spheres X and Y are situated near to each other in a vacuum with their centres a distance of 24 m apart. Point P is at a variable distance x from the centre of sphere X on the line joining the centres of the spheres.

Fig. 5.1 shows the variation with x of the electric potential V due to the spheres at point P.

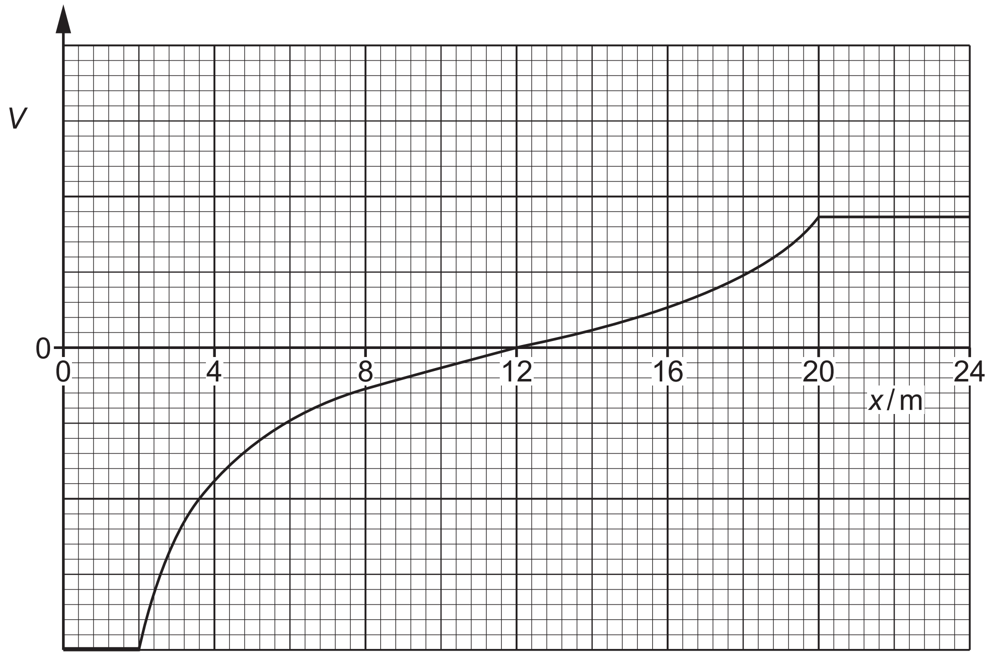

Fig. 5.1

State **three** conclusions that can be drawn about the spheres from Fig. 5.1. The conclusions may be qualitative or quantitative.

1 ....

....

2 ....

....

3 ....

....
[3]

(c) A positively charged particle is placed at point P in **(b)**, such that x = 12 m. The particle is released.

Describe and explain the subsequent motion of the particle.

....

....

....

....

.... [3]

1 **(a)** **(i)** Define gravitational field.

....

.... [1]

(ii) Define electric field.

....

.... [1]

(iii) State **one** similarity and **one** difference between the gravitational potential due to a point mass and the electric potential due to a point charge.

similarity: ....

....

difference: ....

....

[2]

(b) An isolated uniform conducting sphere has mass M and charge Q.
The gravitational field strength at the surface of the sphere is g.
The electric field strength at the surface of the sphere is E.

(i) Show that

$$\frac{M}{Q} = \alpha \frac{g}{E}$$

where α is a constant.

[3]

(ii) Show that the numerical value of α is $1.35 \times 10^{20}\,\mathrm{kg^2\,C^{-2}}$.

[1]

(c) Assume that the Earth is a uniform conducting sphere of mass 5.98×10^{24} kg.
The surface of the Earth carries a charge of -4.80×10^{5} C that is evenly distributed.

(i) Use the information in **(b)** to determine the electric field strength at the surface of the Earth. Give a unit with your answer.

electric field strength = ... unit .... [2]

(ii) State how the direction of the electric field at the surface of the Earth compares with the direction of the gravitational field.

.... [1]

4 **(a)** State Coulomb's law.

....

....

....

.... [2]

(b) A charged sphere X is supported on an insulating stand. A second charged sphere Y is suspended by an insulating thread so that sphere Y is in equilibrium at the position shown in Fig. 4.1.

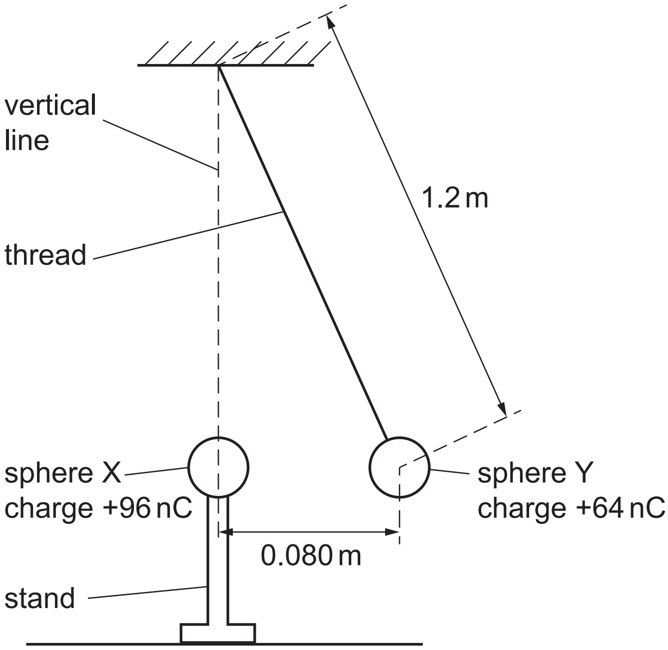

Fig. 4.1

The charge on sphere X is +96 nC and the charge on sphere Y is +64 nC.
Assume that the spheres behave as point charges.

The length of the thread is 1.2 m and the centres of sphere X and sphere Y are separated horizontally by a distance of 0.080 m.

(i) On Fig. 4.2, draw and label all the forces acting on sphere Y.

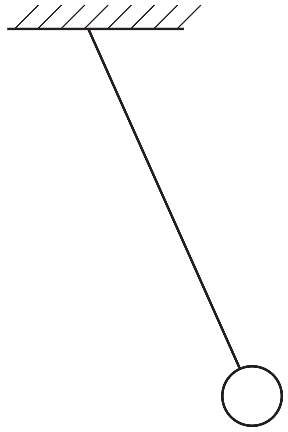

Fig. 4.2

[1]

(ii) Determine the mass of sphere Y.

mass = ... kg [4]

(iii) Calculate the total electric potential energy stored between X and Y.

energy = ... J [1]

(c) An electron enters the region between two parallel plates P and Q, that are separated by a distance of 18 mm, as shown in Fig. 4.3.

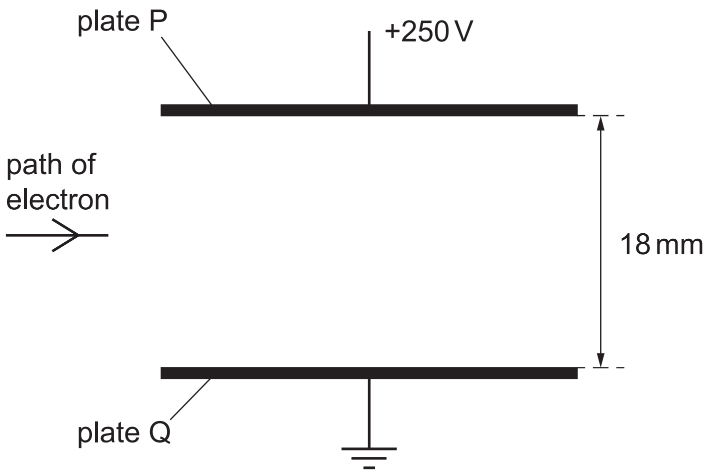

Fig. 4.3

The space between the plates is a vacuum.
The potential difference between the plates is 250 V. The electric field may be assumed to be uniform in the region between the plates and zero outside this region.

(i) State the direction of the electric force on the electron when between the plates.

.... [1]

(ii) Determine the magnitude of the force acting on the electron due to the electric field.

force = ... N [2]

(iii) Explain why the electron does **not** follow a circular path.

....

.... [1]

5 **(a)** Define electric potential at a point.

....

....

.... [2]

(b) An isolated conducting sphere is charged. Fig. 5.1 shows the variation of the potential V due to the sphere with displacement x from its centre.

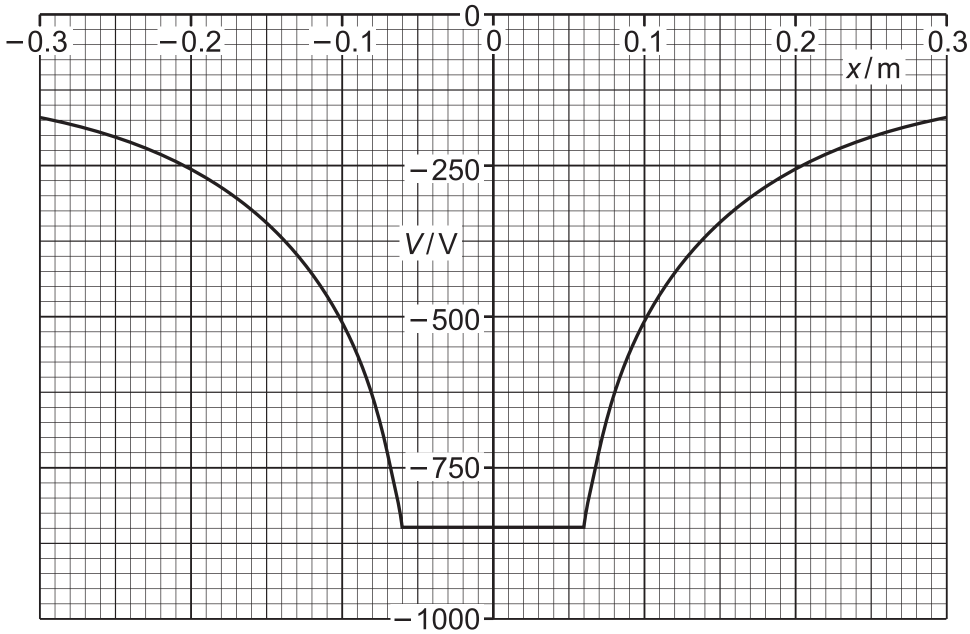

Fig. 5.1

Use Fig. 5.1 to determine:

(i) the radius of the sphere

radius = ... m [1]

(ii) the charge on the sphere.

charge = ... C [2]

(c) Two spheres are identical to the sphere in **(b)**. Each sphere has the same charge as the sphere in **(b)**.

The spheres are held in a vacuum so that their centres are separated by a distance of 0.46 m. Assume that the charge on each sphere is a point charge at the centre of the sphere.

(i) Calculate the electric potential energy E_P of the two spheres.

E_P = ... J [2]

(ii) The two spheres are now released simultaneously so that they are free to move.

Describe and explain the subsequent motion of the spheres.

....

....

....

.... [3]

4 **(a)** State what is indicated by the direction of an electric field line.

....

.... [2]

(b) Fig. 4.1 shows a pair of parallel metal plates with a potential difference (p.d.) of 2400 V between them.

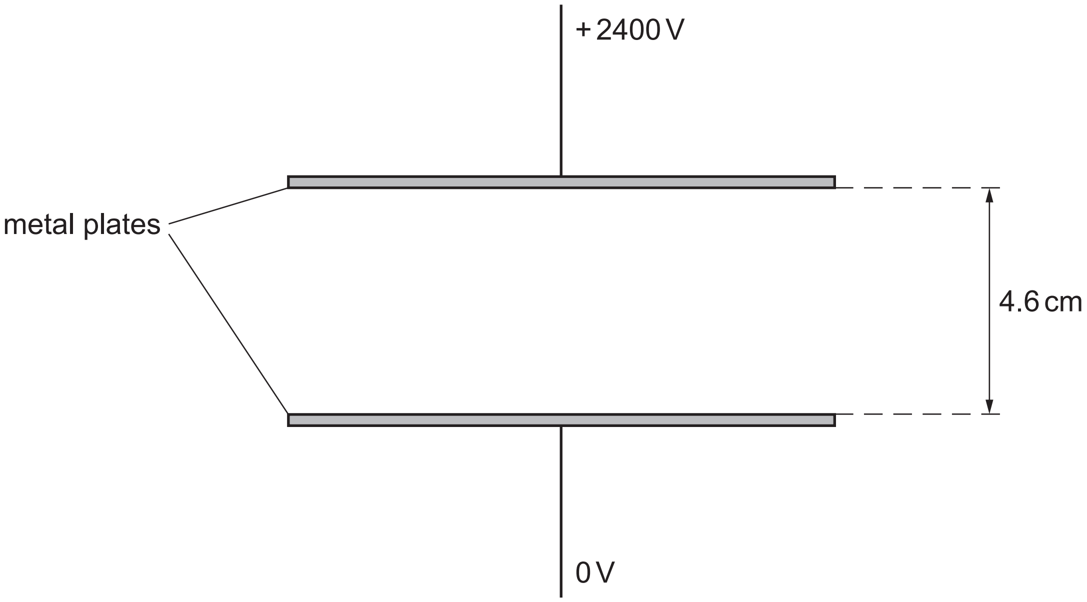

Fig. 4.1

The plates are separated by a distance of 4.6 cm. The plates are in a vacuum.

(i) On Fig. 4.1, draw five lines to represent the electric field in the region between the plates. [3]

(ii) Calculate the strength of the electric field between the plates.

electric field strength = ... NC^{-1} [2]

(c) A moving proton enters the region between the plates from the left, as shown in Fig. 4.2.

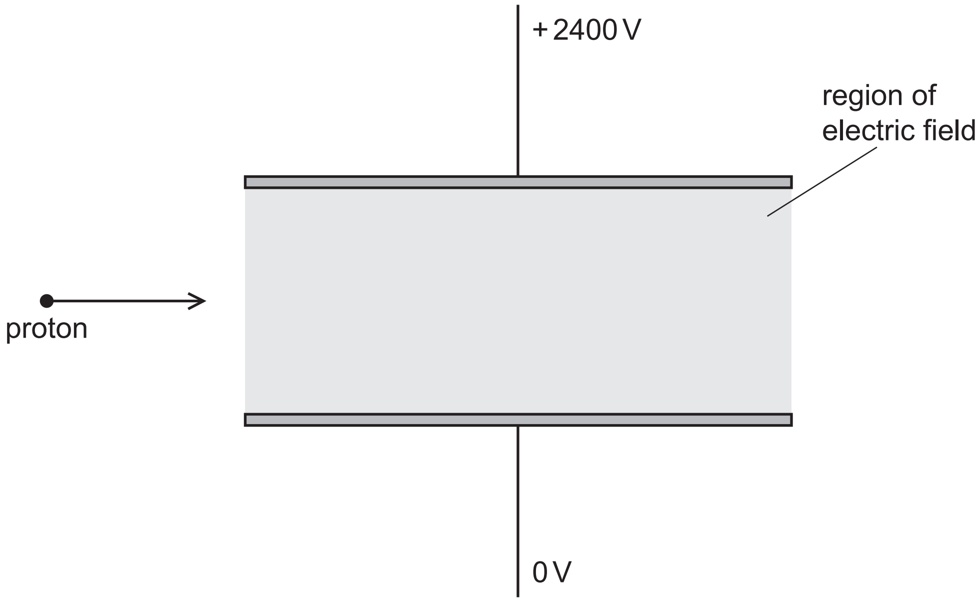

Fig. 4.2

(i) The proton is deflected by the electric field.

On Fig. 4.2, draw a line to show the path of the proton as it moves through and out of the region of the electric field. [2]

(ii) A helium nucleus ($^{4}_{2}He$) now enters the region of the electric field along the same initial path as the proton and travelling at the same initial speed.

State and explain how the final speed of the helium nucleus compares with the final speed of the proton after leaving the region of the electric field.

....

....

....

....

.... [3]